PV Array Simulator Design Based on S3C2440

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Abstract

This paper presents a digital PV array simulator based on ARM controlling which uses S3C2440 as controllor and BUCK as main circuit.The simulator uses the look-up table method to fit the PV array characteristic curve and bode plots to design the system parameters. The experimental results show that the simulator can fully reproduce the PV array characteristic curve and also has a good dynamic response as well.

Keywords

PV array; Simulator; S3C2440;

Introduction

With the conventional energy becoming less and less and the environment pollution becoming more and more serious around the world, the development and utilization of renewable energy is becoming an important way to improve energy structure, reduce environment pollution and ensure energy supply persistently.As one of patterns to utilize solar energy, solar energy generation technology has maintained a sustainable and rapid development in recent years.

The electric power generated by PV array is varying continuous changing with weather conditions. And the equipment is always very big and expensive. so it is necessary to design a low-cost and convenient circuit ,which can replace the PV array to do PV array experiment.

This paper presents a model based hardware PV array simulator ,which emulates the V-I characteristic of a 16W solar module.The simulator uses the S3C2440 as controller , BUCK as main circuit ,look-up table as the method to fit the PV array characteristic curve .The experiment results that the steady-state error and dynamic performance of system is very well.

Mathematical Model of PV Array

In engineering applications, the model of the PV array can be indicates by four parameters under the standard conditions. They are short-circuit current, the open circuit voltage, the current and voltage at the maximum power point. Its V-I equation of characteristic curve is expressed as:

$$I_L = I_{SC}\left[1\text{-}\left(C_1 e^{\frac{V_L}{C_2 V_{OC}}}\text{-}1\right)\right] \tag{1}$$

Where C1 and C2 are evaluated as:

$$\mathrm{C}_1 = \left(1\text{-}\frac{I_m}{I_{SC}}\right)e^{\frac{-Vm}{\mathrm{C}_2 V_{OC}}} \tag{2}$$

$$\mathrm{C}_2 = \left(\frac{V_m}{V_{OC}}\text{-}1\right)\left[Ln\left(1\text{-}\frac{I_m}{I_{SC}}\right)\right]^{-1} \tag{3}$$

Formula (1) describes the V-I curve under the standard irradiance and standard temperature. The IV equation under the general condition (irradiance S, temperature T) can be calculated as the following formula(4)(5)(6)(7)(8)(9).

Firstly, at a given irradiance S, whenever the ambient temperature varies, it causes the PV array temperature to vary. Also the change in S causes change in PV array current and PV array temperature. ΔT in Kelvin and ΔS in Walt per square meter are evaluated as:

$$\Delta T = T - T_{ref} \tag{4}$$

$$\Delta S = S - S_{ref} \tag{5}$$

Then the short-circuit current, the open circuit voltage, the current and voltage at the maximum power point under general condition can be are evaluated as:

$$I_{SC}' = I_{SC}\frac{S}{S_{ref}}\left(1+\alpha\Delta T\right) \tag{6}$$

$$V_{OC}' = V_{OC}\left(1-\gamma\Delta T\right)\ln\left(1+\beta\Delta S\right) \tag{7}$$

$$I_m' = I_m\frac{S}{S_{ref}}\left(1+\alpha\Delta T\right) \tag{8}$$

$$V_m' = V_m\left(1-\gamma\Delta T\right)\ln\left(1+\beta\Delta S\right) \tag{9}$$

Where the typical values of

α, β, γ are $\alpha = 0.0025 / {}^{\circ}C, \beta = 0.5, \gamma = 0.00288 / {}^{\circ}C.$

The V-I equation under the any condition (irradiance S, temperature T) can be obtained from the equation (1).

Description of the Simulator System

Principles of the Simulator System

The schematic block diagram of the PV array simulator is shown in Fig. 1.

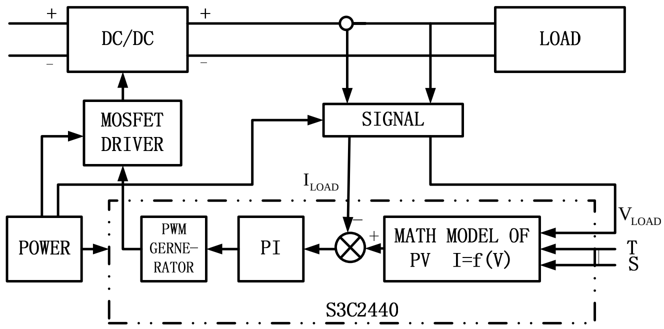

FIG.1 THE PROPOSED PV ARRAY SIMULATOR

As shown in Fig.1, The main circuit is BUCK converter. Duty Cycle D of the BUCK converter can be evaluated as:

$$D = \frac{V_o}{V_i} \qquad (10)$$

where V_o is the input voltage of BUCK, V_i is the output voltage of BUCK.

The circuit consists of a DC–DC buck converter controlled by S3C2440 microcontroller. The S3C2440 microcontroller is responsible for the sampling of the load voltage and current, analyzing data processing, generating PWM pulse, and achieving closed-loop control of the output.

Signal conditioning module includes a voltage sampling signal conversion and current sampling signal conversion. The voltage sampling signal conversion divides the output voltage to less than 3.3V within two voltage-dividing resistors. After followed by the follower, the output voltage is input into the controller to converse analog to digital. The current sampling signal conversion convert the current signal to a voltage signal by using Hall sensor ACS712-05B. Then the output voltage signal is amplified to less than 3.3V through the operational amplifier TLC082 and is input into the controller to converse analog to digital.

The simulator chooses IR2117 as MOSFET driver module. The PWM signal generated by S3C2440 will be converted into a drive signal of 0 to 15V after transforming by the MOSFET driver module.

The power supply module uses L4978, which is the production of ST Microelectronics. L4978 has wide voltage input and output, and its maximum load can reach 2 Ampere, so that it can provide reliable power for each module.

System Control Algorithm

The simulator uses a closed-loop current control scheme. First of all, the simulator samples load voltage through an Analog-to-Digital Converter of S3C2440 microcontroller. Secondly, according to the voltage which is sampled before, the simulator queries the current value corresponding to the PV characteristic curve. It then uses this current value as a command current to compare with the actual current. Finally, the error signal is fed into the current PI regulator, and then the current PI regulator processes it and generates PWM duty cycle to control the MOSFET turn-off, thus the load current is able to track the current instruction. In this way, as long as the load remains the same, you can get both to meet the requirements of both PV characteristic curve and the output voltage and current of Ohm's law. In practical applications, in order to prevent the output oscillation, both the voltage sampling and current sampling use digital filtering to suppress noise and interference.

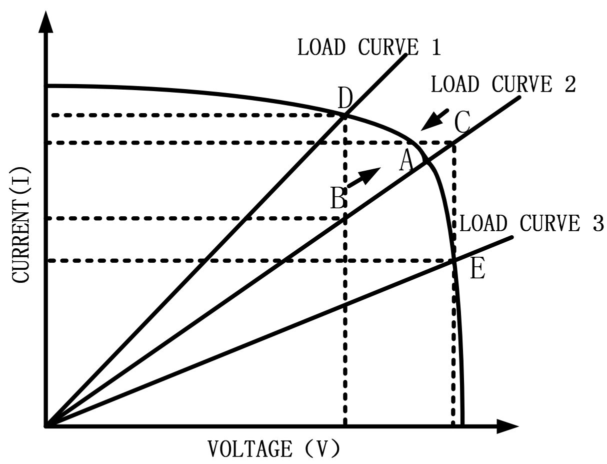

FIG.2 OPERATING POINT ADJUSTMENT

The core of the simulator's control algorithm is how to find the desired operating point and how to work stably at this point. Actually, PV characteristic curve in the first quadrant is monotonically decreasing, and the resistive load curve is a straight line through the origin, so they have a unique intersection, that is, any load on

the PV characteristic curve has a unique operating point. However, Finding operating point is based on the load curve, and changing PWM duty cycle of the BUCK converter can adjusting the output voltage and current for the simulator to work at the operating point. Operating point adjustment is shown in Fig.2.

When adjusting the simulator, if the load changes from load curve 1 to load curve 2, the output voltage remains the same and the Point of load changes from the original point D to point B due to the existence of the filter capacitor. So the controller increases the PWM cycle, thereby increasing the output voltage to make the operating point move to point A. Else if the load changes from load curve 3 to load curve 2, the output voltage remains the same also and the Point of load changes from the original point E to point C. So the controller decreases the PWM cycle, thereby decreasing the output voltage to make the operating point move to point A[3]. In this way, it can ensure that the adjustment process eventually converge to the quiescent operating point.

Hardware Design

The hardware simulator is designed to represent the PV array of which details are $V_{OC} = 20V, I_{SC} = 0.7A, V_m = 16V, I_m = 0.5A$. For the buck converter, a 48V ,6A power supply is used as an input.

The buck converter is designed for continuous current operation with a steady-state peak to peak inductor current (Δi) and voltage ripple (Δv) of 5% and 0.5% respectively.With the chosen f of 50 kHz, the values of the filter elements are designed based on equations

$$\Delta i = \frac{DV_i\left(1-D\right)}{fL} \qquad (11)$$

$$\Delta v = \frac{DV_i\left(1-D\right)}{8LCf^2} \qquad (12)$$

Where L is the filter inductor ,C is the filter capacitor and f is the swithing frequency .

The minimum values of L and C are found as 6.8mH and o.88μF respectively. The inductor is fabricated and its internal resistance r is measured as 0.28Ω. Instead of the calculated minimum C of 0.88μF, 22μF is used so as to improve the transient response under step load conditions.

The converter transfer function $G_p(s)$ and the compensator transfer functions $G_C(s)$ are given as

$$G_P(s) = \frac{V_i}{LC\left(s^2 + s\left(1/CR + r/L\right) + 1/LC\right)} \qquad (13)$$

$$G_C(s) = \frac{K_P s + K_i}{s} \qquad (14)$$

The compensator is so designed that (i) the gain at low frequencies is high to minimize the steady-state error in the output of the converter and (ii) the crossover frequency as high as possible for fast response and the phase margin is large enough to allow good stability.(iii) value of 60° is chosen for phase margin as stability is more important in a grid connected system.

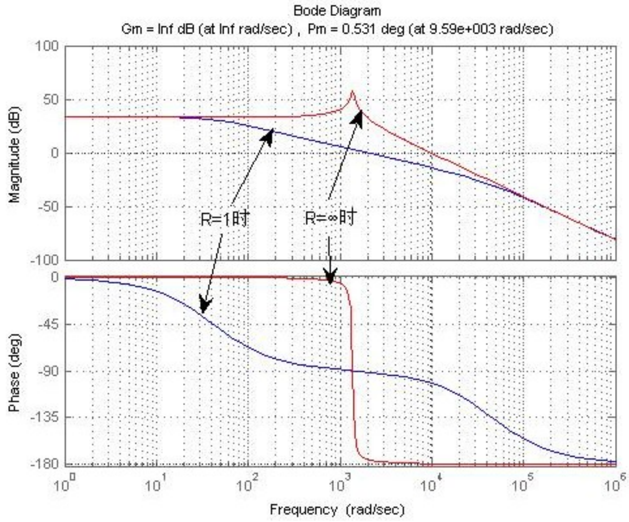

FIG.3 BODE PLOT OF BUCK

(R=1 AND R = ∞)

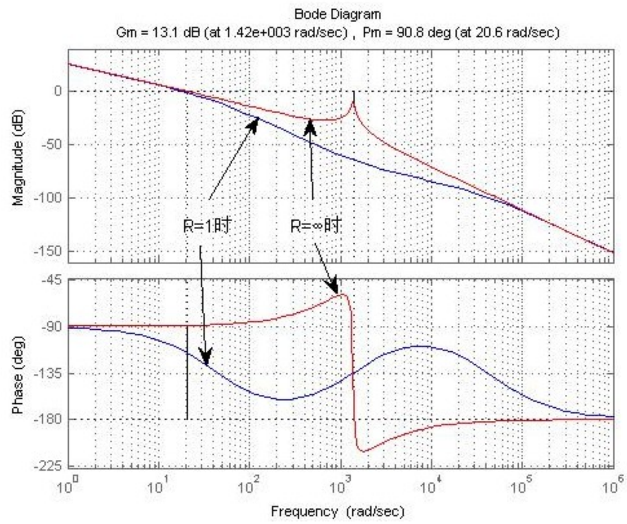

FIG.4 BODE PLOT OF THE PI CONTROLLED BUCK

(R=1 AND R = ∞)

As the Bode diagram shown in Fig.3, the diagram represents a large load(R=1Ω) and no-load(R = ∞) situation. The simulator has the worst stability when R is equal to infinity and phase margin is only 0.531°.it

shows that the resonant frequency is 1370rad/s and the amplitude is 57.5dB at no load situation. So it takes the zero of the $G_C(s)$ s=-1370.

In order to ensure the stability of the system, the amplitude must drop to below 0 dB, and retain a adequate margin, so it takes the amplitude drops 70dB.

The bode plot of the open loop transfer functions $G_P(s)G_C(s)$ of the converter system given in Fig. 4 shows the phase margin as 90.8° at a no-load situation and 66.5°at a large load situation.

Performance of the Simulator

The static V-I characteristics of the simulator has been obtained to validate its performance under steady-state and transient conditions(S=1000W/㎡,T=25℃). For obtaining steady-state characteristics, load test is conducted on the Simulator and the voltage and current values has been obtained experimentally and plotted in the Fig.5.

Fig.6 gives the operating point of different load (R=13.5Ω and R=94.9Ω).when R is equal to 13.5Ω, the experimental result is 9.401V, 0.672A, and the data sheet is 9.356V, 0.693A. When R is equal to 94.9Ω, the experimental result is 19.29V, 0.196A, and the data sheet is 19.26V, 0.203A. The deviation between the experimental data and the data sheet values are found to be below 0.5% and 5%.

Fig .7a and 7b gives the dynamic change in output voltage and current when the there is an increase and decrease in load. The output voltage and current of the simulator for a step change in R from 13.5Ω to 94.9Ω and from 94.9Ω to 13.5Ω. The response time of the simulator is found to be about 25ms for various step changes.

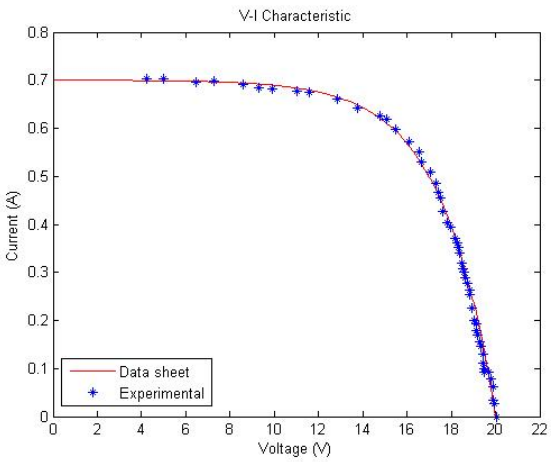

FIG.5 V-I STATIC CHARACTERISTICS

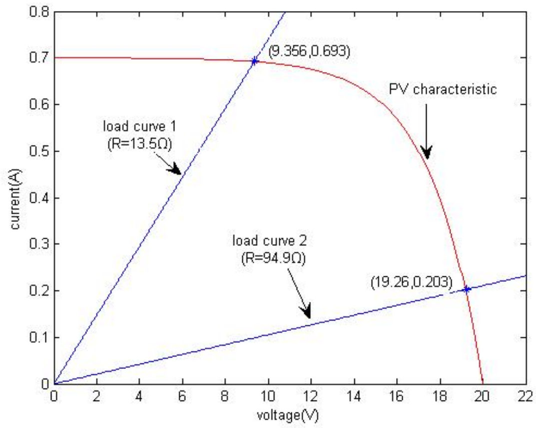

FIG.6 OPERATING POINT (R=13.5Ω AND R=94.9Ω)

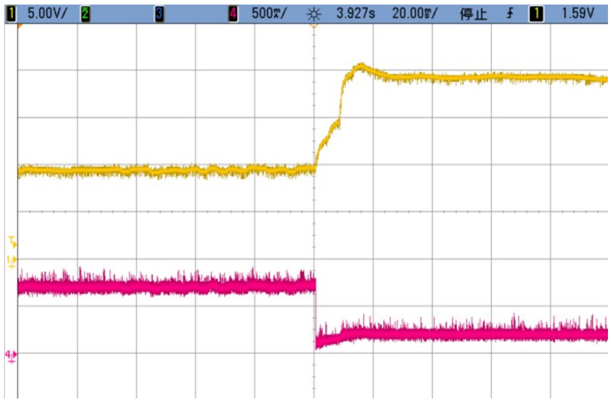

FIG.7a OUTPUT VOLTAGE FOR STEP LOAD CHANGE FROM 13.5Ω TO 94.9Ω UNDER G = 1000 W/m2, Tc= 25℃.(t:20ms/grid)

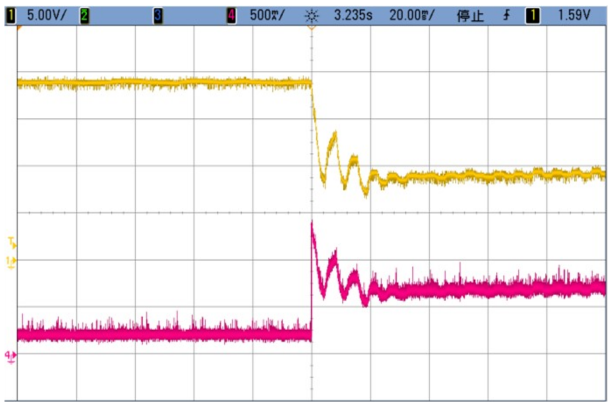

FIG.7b OUTPUT VOLTAGE FOR STEP LOAD CHANGE FROM 94.9Ω TO 13.5Ω UNDER G = 1000 W/m2, Tc= 25℃.(t:20ms/grid)

Conclusion

This paper presents a model based hardware PV array simulator ,which use the S3C2440 as controller , BUCK as main circuit ,look-up table as the method to fit the PV array characteristic curve . By changing the control panel of the open-circuit voltage, short circuit current, the voltage and current of the maximum power point, temperature and irradiance can generate

different solar characteristic curve. The experiment results that the steady-state error and dynamic performance of system is very well. The simulator can be used as an input power source to do PV array experiment.

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